

*QCD Thermodynamics With an Almost Realistic
Quark Mass Spectrum*

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QCD Thermodynamics with an almost realistic quark mass spectrum

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Abstract. We will report on the status of a new large scale calculation of thermodynamic quantities in QCD with light up and down quarks corresponding to an almost physical light quark mass value and a heavier strange quark mass. These calculations are currently being performed on the QCDOC Teraflops computers at BNL. We will present new lattice calculations of the transition temperature and various susceptibilities reflecting properties of the chiral transition. All these quantities are of immediate interest for heavy ion phenomenology.

Keywords: Lattice gauge theory, quark-gluon plasma, critical temperature

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INTRODUCTION AND LATTICE SETUP

The lattice action we use is designed for finite temperature Monte Carlo Simulations. In the gauge sector we use a (2×1) -Symanzik improvement scheme which eliminates all cut-off effects of order $\mathcal{O}(a^2)$, where a is the lattice spacing. For the fermions we use the staggered fermion formulation. On top of that we add an improvement term which restores the rotational symmetry of the free quark propagator on the lattice up to order $\mathcal{O}(p^4)$ in the momentum p [1]. In order to improve the flavor symmetry, which is violated in the staggered fermion formulation, we smear the gauge field which is used in the standard part of the fermion action. The procedure involves either only three link terms (p4fat3) or up to seven link terms [2] (p4fat7). While the p4fat3 action was used for thermodynamical calculation earlier [3, 4], the combination of the p4-term and seven link smearing is used here for the first time in thermodynamic calculations [5, 6].

We perform simulations with three degenerate quark flavors as well as with 2 light and one heavy quark flavor. The lattices have temporal extent $N_t = 4, 6$, which corresponds at the critical temperature (T_c) to a lattice spacing of $a \approx 0.13$ fm and 0.22 fm respectively. The lattice extent in spacial direction is $N_s = 8, 16, 32$. To determine the scale, we perform zero temperature simulations on $16^3 \times 32$ lattices. These calculations are being performed on the QCDOC Teraflops computers at BNL.

THE CRITICAL TEMPERATURE

The observables we calculate at present are the gauge action, the Polyakov loop and the chiral condensate. For each of these quantities we calculate also its susceptibility. Using the multi-histogram reweighting technique [7] we combine the statistics of Monte Carlo runs at different couplings β . Results for the chiral condensate and chiral susceptibility

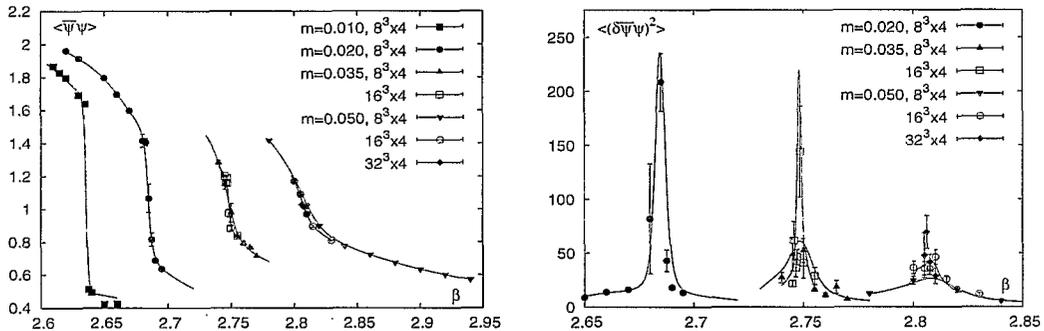


FIGURE 1. The chiral condensate and (left) and the chiral susceptibility (right) for the p4fat7 action with three degenerate flavor and $N_t = 4$. Data points are the individual Monte Carlo runs; solid curves are from multi-histogram reweighting.

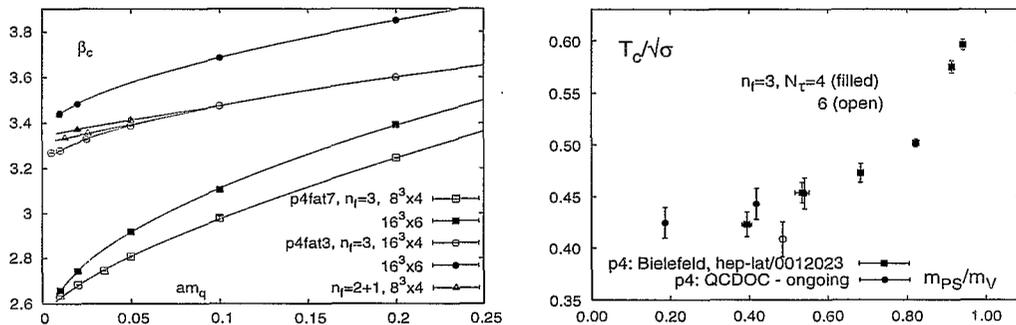


FIGURE 2. The critical couplings vs. the bare quark masses for different actions and lattice sizes (left) and the critical temperature in units of the string tension (σ) as a function of the ratio of pseudo-scalar and vector meson masses (right).

of the p4fat7 action in the case of three degenerate flavors and $N_t = 4$ are shown in Fig. 1. As expected the chiral transition becomes more pronounced for smaller quark masses. The peak heights of the susceptibilities increase and a volume dependence becomes visible. We define the critical couplings (β_c) as the peak positions of the chiral susceptibilities. However, we find that the peak positions of all susceptibilities agree within our statistical accuracy. In Fig. 2(left) we show a comparison of β_c for the two actions and temporal lattice sizes analyzed so far. The solid lines are fits to a power law. We find that the separation between the $N_t = 4$ and $N_t = 6$ critical lines is much smaller for the p4fat7 action than for the p4fat3 action. In fact, for small quark masses the critical couplings for $N_t = 4$ and 6 almost coincide which suggests the presence of a nearby bulk transition in the parameter space defined by the p4fat7 couplings. This also leads to the onset of first order transitions at pion mass values larger than those found for the p4fat3 action. All this makes the p4fat7 action less suitable for studies of thermodynamics¹

¹ We note that we have used a p4fat7 action with tree level coefficients and have not introduced tadpole improvement factors as it is done for the asqtad action [2].

as the extrapolation to the continuum limit will become more difficult, i.e. will require larger N_t .

The two $(2+1)$ -flavor lines shown in Fig. 2(left) are lines at constant strange quark mass. The lines corresponds to $am_s = 0.065$ and $am_s = 0.1$ for the lower and upper curve respectively. A bare strange quark mass of $am_s = 0.065$ approximately corresponds to the physical strange quark mass.

At each critical coupling β_c we perform a zero temperature scale setting calculation on a $16^3 \times 32$ lattice, where we calculate hadron masses and heavy quark potentials. From the potential we extract the Sommer scale r_0 as well as the string tension σ by fitting the lattice data with the usual Ansatz $V(r) = -\alpha/r + \sigma r + const$. We show some preliminary results of the critical temperature in units of the string tension in Fig. 2(right). The quark mass dependence of the critical temperature for p4fat3, $N_t = 4$ and $n_f = 3$ is consistent with the earlier calculations [4]. The chiral extrapolation of $T_c/\sqrt{(\sigma)}$ with $(m_{PS}/m_V)^2$ yields results consistent with earlier findings of $T_c/\sqrt{(\sigma)}|_{m=0} = 0.407(15)$ [4]. The chiral extrapolation for p4fat7 gives smaller values: $T_c/\sqrt{(\sigma)}|_{m=0} \lesssim 0.4$ and $\lesssim 0.35$ for $N_t = 4$ and $N_t = 6$ respectively. Furthermore, the N_t dependence of the transition temperature is much stronger for p4fat7 than for p4fat3. This again indicates a possible bulk transition in the vicinity of the chiral limit of the p4fat7 action.

OUTLOOK

The still ongoing determination of the critical temperature is part of a detailed study of the thermodynamics of $(2+1)$ -flavor QCD. As soon as we have reliable chiral extrapolations for $N_t = 4$ and $N_t = 6$ we will add a $N_t=8$ calculation at selected quark mass values and try to perform the extrapolation to the continuum limit. Moreover we will perform a study of the equation of state with an almost realistic quark mass spectrum.

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